I. EXECUTIVE SUMMARY

ASSESSING IMPACTS OF SELENIUM ON RESTORATION OF THE SAN FRANCISCO BAY-DELTA ECOSYSTEM. *S. N. Luoma*, US Geological Survey, Menlo Park, CA; *G. A. Cutter*, Old Dominion University, Norfolk, VA; *N. S. Fisher*, SUNY, Stony Brook, NY.; *D. E. Hinton*, Univ. California at Davis, CA 95616

Project Description: Some of the most contentious restoration issues in the Bay-Delta revolve around selenium (Se) contamination. Selenium has been implicated in numerous cases of reproductive failure and loss of fish, waterfowl and crustacean populations (Ref. 24). In the Bay-Delta, Se concentrations high enough to cause such damage occur in sturgeon, diving ducks and dungeness crab (Ref. 19). Restoration of the Bay-Delta could be ineffective without resolution of selenium-related issues; uninformed restoration decisions could worsen Se contamination.

The chemical speciation of Se determines its fate, cycling and biological impacts (Fig. 1). Speciation differs among the potential anthropogenic sources of Se input to the Bay-Delta. Selenium can occur in high concentrations in agricultural irrigation drainage, which is discharged to the Bay-Delta from the San Joaquin River. Selenate (Se(VI)) is the principal dissolved form in this source (and in the Sacramento River); particulate forms can include elemental Se(0) (Ref. 1). Refineries are another important source. Their waste waters include a high percentage of dissolved selenite (Se(IV)). Within the Bay this Se(IV) is efficiently converted to particulate organo selenide by biological uptake (Fig. 1). Dissolved organic selenide (Se(-II)) is regenerated internally in the Bay-Delta and biogeochemical reactions in the water column can generate particulate Se (IV+VI). These forms are indicative of recycled Se (e.g. from sediments) (Ref. 3). Thus, determinations of Se fluxes and speciation from rivers, effluents and pore waters, accompanied by Se determinations within the ecosystem at different times, allows determination of the sources of Se to the Bay-Delta. Each form of Se also has a different biological availability (Ref. 14). Quantitative understanding of how changes in form affect Se uptake by critical species allows inferences about the biological significance of the different sources. Selenium magnifies in the food web as plants are eaten by their consumers and consumers are eaten by their predators (Ref. 14, 27). The highest trophic level species are the first to be threatened. However, all predators do not appear to be equally at risk, perhaps because the efficiency of Se transfer differs among food webs. Quantitative comparisons of trophic transfer can allow identification of species most and least at risk.

Selenium issues are also changing in complex ways. Refineries are reducing their Se discharges, but contamination has worsened in clams (a critical link to the threatened predators in the food web) (Ref. 10)(Fig. 2), and perhaps in sturgeon and diving ducks (Fig. 3). The causes of the recent increases in contamination are not known, but could involve biological processes (e.g. a new resident species of benthos now dominates Suisun Bay), geochemical processes (e.g. speciation of Se may be changing), physical influences (e.g. contamination may increase at lower river inflows) or changing inputs (e.g. increased agricultural inputs). Where complex factors interact in changing circumstances, models can aid understanding of issues and can project outcomes of alternative management strategies.

We are proposing a substantial, uniquely integrated, ecosystem evaluation of Se in the Bay-Delta, that will lend itself to developing models useful in Se management strategies. The

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study will deliver the following products:

- A quantitative description of how the rivers, agricultural drainage, refineries, and recycling contribute to Se concentrations in the Bay-Delta.
- Determination of how changing sources might affect Se tissue concentrations in primary consumers (bivalves and copepods) under different river inflow regimes.
- Linkage of Se concentrations in primary consumers to uptake by predators and inferences about the potential for adverse effects on sturgeon, diving ducks, striped bass and delta smelt.
- A direct determination of whether Se affects reproduction and development in sturgeon.
- Models, developed from the above, that can forecast outcomes of alternative Se remediation/restoration strategies or can evaluate the status of Se issues.
- A baseline of monitoring data against which to evaluate future changes in Se contamination.

Approach/Tasks/Schedule: The study will be conducted over three years. Rivers and effluents will be sampled monthly to determine Se inputs (Fig. 4). Concentrations and subcellular distributions of Se will be determined in clams and speciation will be determined in water and suspended particles at high river flow and low river flow each year. These data will help identify sources of input (from speciation signatures) and Se trends in the food (clams) of bottom feeders like sturgeon and diving ducks. Porewater Se will be analyzed to determine recycling from sediments. Shallow water habitat will be surveyed in Suisun Bay and in the Delta to determine speciation, recycling and bioavailable concentrations in this critical habitat.

Using radiotracer protocols (Ref. 14, 16), the biological availability of each of the important dissolved and particulate forms of Se in the Bay-Delta will be experimentally evaluated (Fig. 5). Models will be developed from these studies to predict Se bioaccumulation under different input conditions in clams, copepods and oysters (a potential husbandry in a restored ecosystem). We will determine trophic transfer of Se from copepods to striped bass larvae and the mid-trophic level fish *Menidia menidia*; and from clams to sturgeon. Model projections will be compared to field data collected above and to Se concentrations determined in striped bass, smelt and sturgeon, as part of a mercury cycling study being proposed by USGS. Effects of Se trophic transfer on development of sturgeon eggs will also be evaluated.

Justification/Budget/Qualifications/Coordination: Simple elimination of all sources of Se input to the Bay-Delta is not feasible (even if it were technically possible), partly because no convincing integrated view exists of the significance of the problem and its different sources. We are proposing to work with CALFED to resolve knowledge gaps and use models and monitoring to aid management of Se controversies that might impede the restoration process. The PI's have stature, substantial experience and no vested interests in the local Se issues. This study will bring to bear their specific experience with Se and the Bay-Delta. It will take advantage of local USGS infrastructure and matching support. Drs. Cutter and Fisher are recent recipients of a National Science Foundation grant wherein they will be examining some mechanistic details of Se cycling in the SF Bay. We are asking CALFED to build on the opportunity provided by the fundamental NSF and USGS research, and support a related study directly applied to questions of Se impacts on restoration of the Bay-Delta. We will coordinate this study with other programs funded by CALFED, especially including other USGS proposals. We are requesting from CALFED, spread over three years, a total of $1,588,709.